Nuclear Power – Bridging the Gap

NHJES "Sustaining Our Future" Conference

October 6, 2011

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Agenda

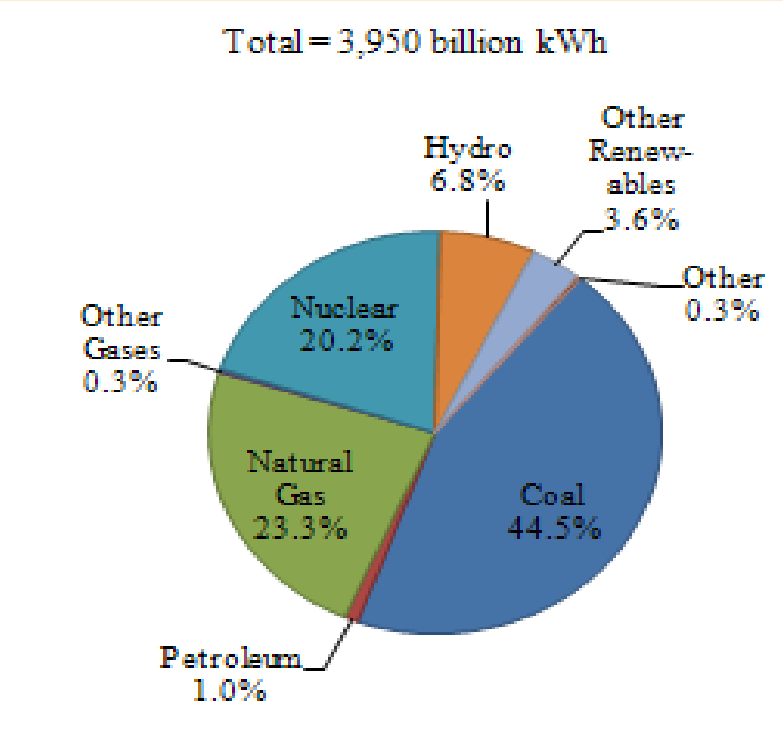
1. Electrical Power Generation Sources
2. Discussion on “Sustainable” Generation
3. Nuclear Power Specifics
4. Nuclear Power Future Trends
5. Spent Nuclear Fuel
6. Overview of March 2011 Fukushima Daiichi Event

Electrical Power Generation

Electrical Power Generation

2009 total - 3,950 billion KWH

- Coal – 44.5%
- Natural Gas – 23.3%
- Nuclear – 20.2%
- Hydroelectric – 6.8%
- Wind – 1.9%
- Other renewables – 1.7%
- Petroleum – 1.0%
- Other – 0.6%



Electrical Power Generation

"PR" Trends - 2009 compared to 2008

- Wind Power - increased 33.5%
- Hydroelectric - increased 7.3%
- Natural gas - increased 4.3%
- Solar - increased 3.1%
- Nuclear - decreased 0.9%
- Coal - declined 11.6%
- Petroleum - decreased 15.8%

Electrical Power Generation

"Absolute" Trends - 2009 compared to 2008

- Natural gas - increased 1.0% (22.3% to 23.3%)
- Hydroelectric - increased 0.5% (6.3% to 6.8%)
- Wind Power - increased 0.5% (1.4% to 1.9%)
- Nuclear - decreased 0.2% (20.4% to 20.2%)
- Coal - declined 5.8% (50.3% to 44.5%)

Sustainable Power Discussion

Sustainable Power Generation

What constitutes “sustainable” generation?

- Fuel source – “infinite supply”
- Fuel source – easy to obtain
- No impact on environment to install
- No impact on environment to operate
- No impact on “quality of life” for
  - ✓ Nearby residents
  - ✓ Future generations

Sustainable Power Generation

How to get to a “sustainable” future?

- Research to develop new technologies
- Use all current available technologies
  - ✓ Maximize positive aspects
  - ✓ Minimize negative aspects

Nuclear Power Specifics

Nuclear Power Specifics

Just the facts – 2010 data

- Operational reactors worldwide – 342
- Operational reactors in US – 104
- US installed capacity - 100.7 GWe
- France installed capacity – 63.1 GWe
- Japan installed capacity – 47.7 GWe

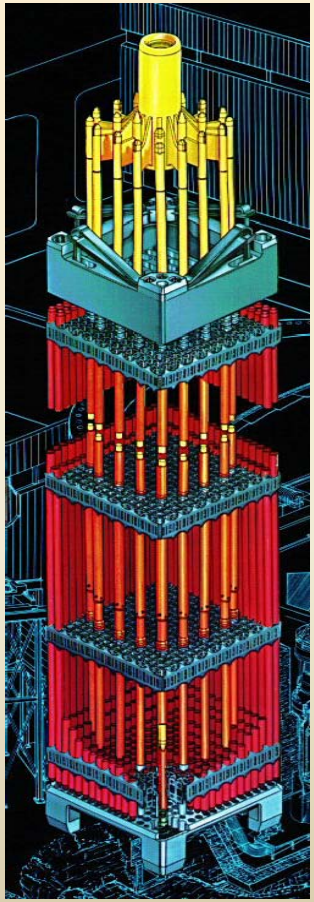
Nuclear Power Specifics

Nuclear fuel specifics

- Fuel source is “enriched” $_{92}U^{235}$
- Fuel pellets are a ceramic based material
- A fuel pellet is about the size of a pencil eraser
- Pellets stacked in metal tubes to form a fuel rod
- Fuel rods combined into a fuel assembly

Nuclear Power Specifics

Typical Fuel Assembly - Westinghouse



Nuclear Power Specifics

Nuclear fuel specifics (continued)

- Seabrook data
  - ✓ 193 fuel assemblies (F/As)
  - ✓ 1300 MWe Output
  - ✓ Operates about 18 months between refueling outages
  - ✓ Typically loads between 80 to 84 new F/As each outage

Nuclear Power Future Trends

Nuclear Power Future Trends

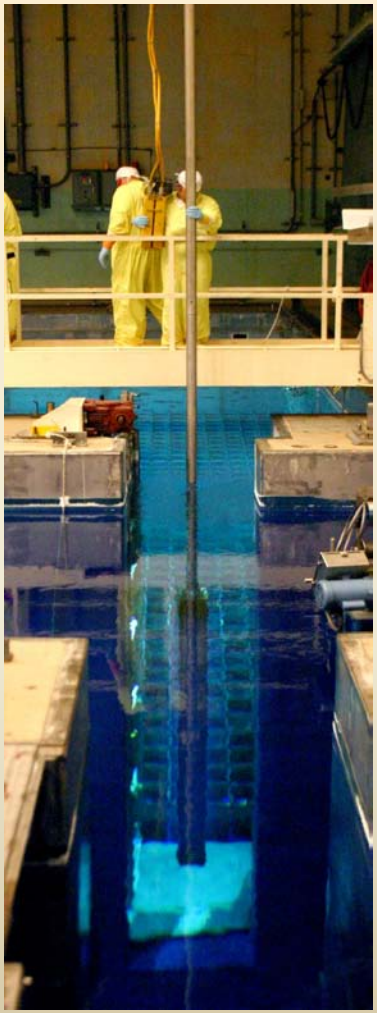
- Plants applying for 20 year license extension
- Plants applying for power uprates (between 1% to 18%)
- Evolutionary designs receiving Nuclear regulatory Commission (NRC) review:
  - ✓ “Standardized” designs
  - ✓ More “passive” safety features
  - ✓ Combined or “one-step” licensing process

Spent Nuclear Fuel

Spent Nuclear Fuel

Spent Nuclear Fuel

- Also referred to as “used”, “waste”, “depleted”
- Remote handling through water used to:
  - ✓ Provide for radiation shielding
  - ✓ Provide for cooling the decay heat



Spent Nuclear Fuel

What is decay heat?

- Once a reactor is shutdown, radioactive decay of fission products continues.
- Fission product radioactive decay produces heat (referred to as decay heat)
- Decay heat decreases exponentially
- Need to provide cooling for many years following shutdown

Spent Nuclear Fuel

A review of radiation in our environment

- Our earth is naturally radioactive
- We are exposed to radiation on a day to day basis from many sources:
  - ✓ Cosmic radiation
  - ✓ Type of house construction (wood or stone)
  - ✓ Amount of plane travel
  - ✓ Medical procedures
- Biological effects same for “natural” vs “man made”

Spent Nuclear Fuel

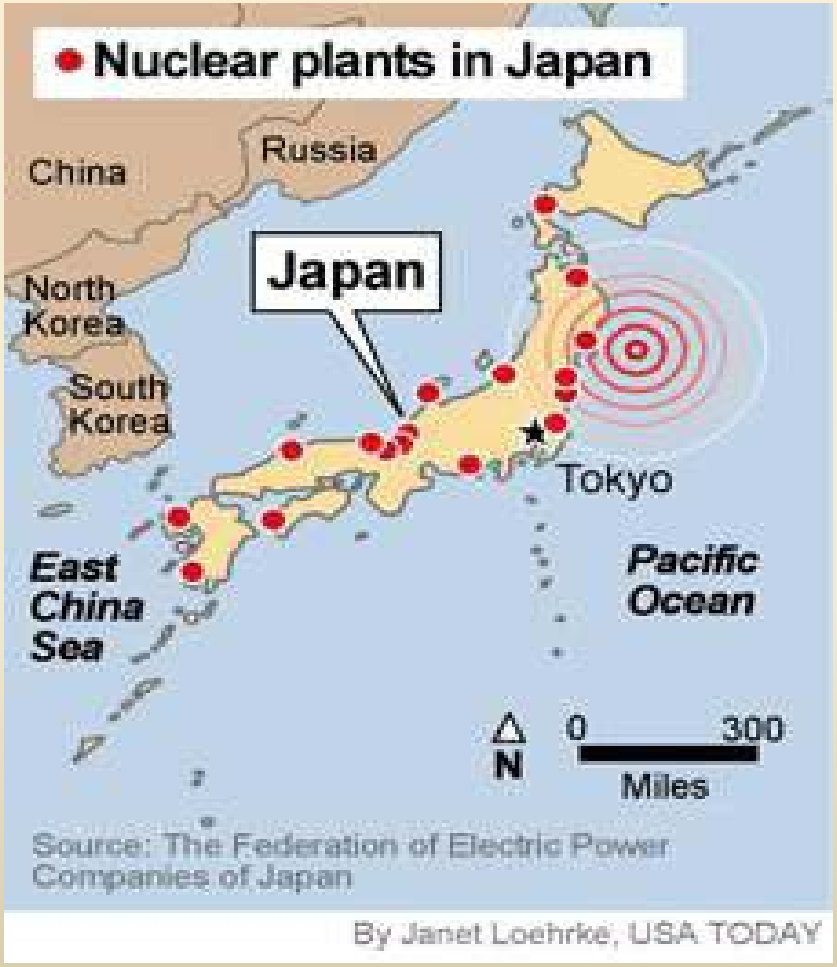
- (-) Radioactivity levels high – biological hazard
- (-) Decay heat – need to continue to cool
- (+) “Limited” volume to dispose
- (+) Fission products from power production concentrated in ceramic fuel pellets
- (+) Fuel can be isolated by storage in engineered containers buried under ground

Fukushima Daiichi

March 2011 Fukushima Daiichi Event

- Six reactors at the site
- Status on March 11, 2011:
  - ✓ Units 1, 2, and 3
    - ❖ Operating
  - ✓ Unit 4
    - ❖ Shutdown, no fuel in reactor
  - ✓ Units 5 and 6
    - ❖ Shutdown, fuel in reactor vessel

March 2011 Fukushima Daiichi Event



Earthquake at 2:46 on Friday, March 11, 2011

March 2011 Fukushima Daiichi Event

- Earthquake measured 9.0 on the Richter scale
- Nuclear plants at Fukushima-Daiichi, Fukushima-Daini and Onagawa shut down
  - ✓ Emergency power systems activated
- Earthquake caused a tsunami which hit the east coast of Japan within an hour

March 2011 Fukushima Daiichi Event

- Fukushima Daiichi all emergency diesel generators started, as designed.
- Site designed to withstand tsunami waves of 5.7 meters high.
- Actual tsunami waves estimated over 14 meters.

March 2011 Fukushima Daiichi Event

- Tsunami affects emergency diesel generator power systems
  - ✓ All fail except one which provides emergency power to Units 5 and 6
  - ✓ Remaining Units lose all AC power
  - ✓ Result is extended loss of all AC power to Units 1 through 4

March 2011 Fukushima Daiichi Event

- Units 1, 2, and 3
  - ✓ Fuel in reactor vessel heats to point of fuel damage
- Units 1, 2, 3, and 4
  - ✓ Spent fuel pools – active cooling lost
  - ✓ Water inventory degrades due to heat up boiling of fuel

March 2011 Fukushima Daiichi Event

- Overall site issues
  - ✓ Radiological releases occur
  - ✓ Hydrogen gas explosions causes damage to Unit 1, 2, and 3 buildings
- Units 1, 2, 3, and 4
  - ✓ Long term plan to achieve a stable cold shutdown condition.
- Units 5 and 6
  - ✓ Remain in a cold shutdown condition

March 2011 Fukushima Daiichi Event

- September 2011 WHO Information
  - ✓ Early actions in response to events at the Fukushima Daiichi in line with the existing recommendations for radiation exposure.
  - ✓ Evacuated individuals within a 20-kilometre radius evacuated.
  - ✓ Those between 20 km and 30 km asked to evacuate voluntarily.

March 2011 Fukushima Daiichi Event

- September 2011 WHO Information
  - ✓ There is a risk of radioactive exposure as a result of contamination in food
  - ✓ However, contaminated food would have to be consumed over prolonged periods
  - ✓ Radioactive iodine and cesium concentrations above Japanese regulatory limits have been detected in some food
  - ✓ Japanese authorities have implemented measures to prevent sale and distribution

March 2011 Fukushima Daiichi Event

- US Nuclear Industry
  - ✓ Utilities have done short term assessments of their plants to assess vulnerabilities
  - ✓ Regulator has conducted a short term review and concluded that US plants are safe and can continue to operate
  - ✓ Regulator performing more detailed longer term review

Closing Thoughts

- US nuclear plants continue to deliver 20% of base load electrical demand
- Spent fuel disposal issues
  - ✓ "Limited" volume requiring disposal
  - ✓ Issues are mainly political – technical issues can be addressed
- New plants to be licensed by a "one-step" process

Closing Thoughts